A Generalized Coordination Setting Method for Distribution Systems with Closed-loop

Kang-Le Guan, Seung-Jae Lee, Myeon-Song Choi

Abstract—The protection issues in distribution systems with open and closed-loop are studied, and a generalized protection setting scheme based on the traditional over current protection theories is proposed to meet the new requirements. The setting method is expected to be easier realized using computer program, so that the on-line adaptive setting for coordination in distribution system can be implemented. An automatic setting program is created and several cases are taken into practice. The setting results are verified by the coordination curves of the protective devices which are plotted using MATLAB.

Keywords—protection setting, on-line system analysis, over current protection, closed-loop distribution system

I. INTRODUCTION

WITH the rapid development of modern industry, nowadays the power system is expected to provide higher reliability to avoid the losses caused by even a temporary power outage. One way to ensure the reliability, which is popular and being extensively studied by the electrical engineers, is to connect the current radial distribution system, as well as integrating DG sources to realize closed-loop operation distribution system [1]. And thus the concept of smart grid was proposed to describe it. Apparently, besides the reliability improvement there are more benefits that we can obtain from the smart grid. In smart grid, more renewable power can be utilized, higher energy efficiency can be achieved and more advanced IT technologies would be adopted and so forth. The smart grid including the corresponding protection techniques [2], [3] has been widely studied. To be specific, in this paper only the new protection issues of the distribution systems with open and closed-loop rather than the smart grid will be discussed.The guiding philosophy of the proposed generalized protection setting method is to search the setting paths from every substation at first, and treat them as radial feeders equivalently. And then, the factors that should be taken into account while designing the protection scheme are summarized as following: (1) load increase when protective devices were tripped, (2) fault current contribution factor from different sources, (3) coordination time interval insufficient for too many protection devices in series, (4) one device coordinating with two or more backups, and (5) bidirectional load current and fault current. In this paper, all of these mentioned problems will be analyzed in more detail, and corr- esponding solutions are put forward also. It is necessary to keep in mind that the protection scheme is expected to act as the backup for the communication-assisted protection system [2], which is new technologies of relay protection which are considered as the predominant technique for the smart grid.

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Section II presents the new protection problems of the closed-loop distribution system. Section III introduces the setting method. Section IV gives a case study as well as the result verification and at last section V comes up with conclusions.

II. NEW PROTECTION ISSUES IN THE DISTRIBUTION SYSTEMS WITH OPEN/CLOSED-LOOPS

A typical distribution system with loops is shown in Fig. 1. It is realized by connecting several traditional radial feeders and allowing closed-loop operation mode. A similar and more detailed system was constructed in reference [4].

In the example system, the original radial feeders supported by S/S #1, S/S #2 and S/S #3 respectively were connected by tie switches to improve service reliability. Normally, only two of the sources would be put into service to drive the closed-loop operation. The protective devices around the loop should coordinate with its backup devices via satisfying the requirements between their operating curves (inverse-time curve) in both direction, thus the directional unit [5], [6] is necessary for each device. Based on the over current protection theories [7], the protection objective of such a system would be: (1) selectivity: limiting the outage area to be minimal when fault occurs, (2) speediness: clearing the fault as fast as possible, (3) sensitivity: detecting any prospective fault in its protection zone, and (4) reliability: no mal operation for the faults in the overlap zone.
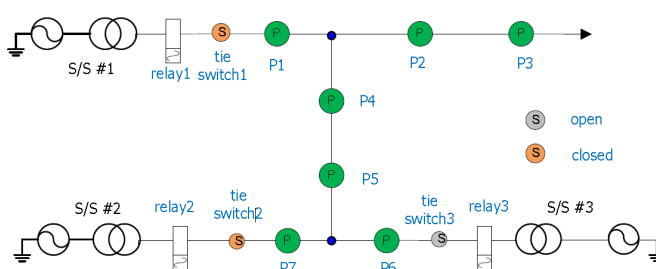

Fig. 1 A typical closed-loop distribution system

To meet the preceding indicated objectives, there are several vital aspects should be analyzed and the new features of these aspects in the distribution systems with closed-loop are discussed in detail as below.

A. Load current

After the radial systems were connected and the closed-loop is put into practice, the loads will be shared by the sources that are in service at the same time. When the system operates normally, the load current passes each protective device is similar with the current under open loop operation mode. However, if fault occurs, such as the fault between relay1 and P1 (the most severely condition) in Fig. 1, both relay1 and P1 will trip to isolate the fault.

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A new operating scheme such as close tie switch3 is going to be created and put into operation. But before the new scheme has been carried out, all the loads will be carried by S/S #2 only, that means the load current will change very different from the normal state and the protective devices should be capable of handling with such a condition.

Therefore, the maximum load current that may go through a protective device in the closed-loop distribution systems should be the sum of all its downstream loads without regarding to the load sharing by the source in the other sides. And this value can be used to determine the lower limit of the pickup current of the relevant protective devices.

B. Fault current

To assure that the protective devices will see all of the faults, the pickup current should be less than the possible minimum fault current that may happen in its protection zone. So the minimum fault current in its protection zone will used to determine the upper limit of the pickup current. Usually the protection will extend into adjacent lines, thus one more thing need to be guaranteed is that the backup does not operate for the faults in the overlapping area unless the primary protective device fails to clear the fault.

In the closed-loop operation mode, because of the current distribution, some problems will come up while using the minimum fault current constraint. For instance, P1 and P4 will back up for P2 in Fig.2, the minimum fault current that P1 and P4 should be able to detect has high possibility to occur at the end of the line after P2. If $Z_4 \gg Z_1$, the upper limit (depends on the minimum fault current) for P4 would be too small to be larger than the lower limit of the pickup current. And such a situation is inevitable in the closed-loop distribution system.

$$I_1 = \frac{Z_4}{Z_1 + Z_4} \times I_2$$

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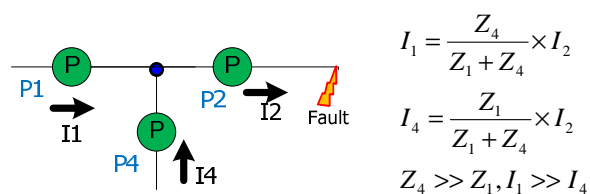
$$Z_4 \gg Z_1, I_1 \gg I_4$$

Fig. 2 Fault current distribution

The best way to solve this problem is calculating the fault current of P4 assuming that P1 is open. And just check the constraint using such a result as the upper limit. That is to say, when there is fault in the primary protection zone of P2 and unfortunately, P2 failed to clear the fault due to some unpredictable reasons, P4 is expected to operate after P1 tripped.

The same problem exists whenever it comes to calculating the current goes through the backup device while the fault is in the primary protection zone. Under that condition, the current distribution factors which depend on system configuration need to be applied. The distribution factor can be calculated following the circuit theory taking use of the system configuration and impedances.

C. Sacrificing devices

Due to restriction of the coordination time interval (CTI) limit [1] and the operating time requirement (general around 30 cycles) for protecting the line near the substation, the number in series in one distribution line is limited also. The coordination curves are expected to be like the sketches shown in Fig. 3, from which we can see it is very difficult to coordinate all the protective devices in the line if there are too many of them because of the limit of CTI.
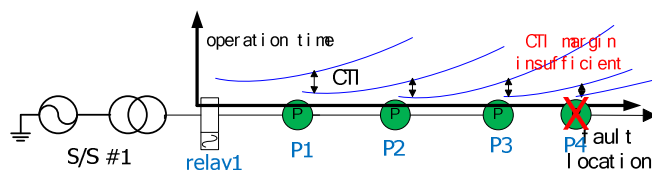

Fig. 3 CTI insufficient for one setting path

In the distribution system with closed-loop we built, the problem can be a common thing. To obtain the coordination of the devices, the proposed method is to select some of the protective devices as the prior ones, and coordinate these devices firstly, and then set the ones of less priority according to the previously set ones (simultaneously operation is allowed and the selectivity of the less priority is sacrificed [8]). The process of the selection is based on the load capacity in the primary protection zone of the protective device. A higher load capacity generates higher priority.

D. Multi backups for one protective device

As shown in Fig.2, in a closed-loop system, some devices like P2 would have more than one backup (here are P1 and P4), and with one set of setting it should be capable of coordinating with all its backups. In such a case, the primary device will be set according to every backup respectively. And then, remain the setting of the backups unchanged, but the fastest operating setting of the primary protective device will be searched and reloaded to it as the final setting. In this way, the CTI requirements between the primary and backup devices are all ensured.

E. Bidirectional load current and fault current

The multi source in the system will bring in bidirectional load current and fault current, thus the directional element for each protective device is necessary to guarantee that it will not operate while a normally load current or a reverse fault current goes through. And in order to cope with the fault current that may flow in both directions, the devices in the loop setting path should have two sets of setting. Only the excessive current in the tripping direction will start the relay.

III. THE GENERALIZED SETTING METHOD FOR COMPUTERIZED AUTOMATION

The setting method is based on the conventional over current relay protection theory [7]. To be brief, the basic things are omitted here, and the protective devices are instantiated to be over current relay (OCR) and automatic circuit recloser (Rec) only. All the procedures will handle with phase fault and ground fault respectively. The system in Fig.1 is referred to illustrate the algorithm.

The simplified processing flow of the setting method is shown in Fig. 4. And some vital procedures are discussed subsequently.
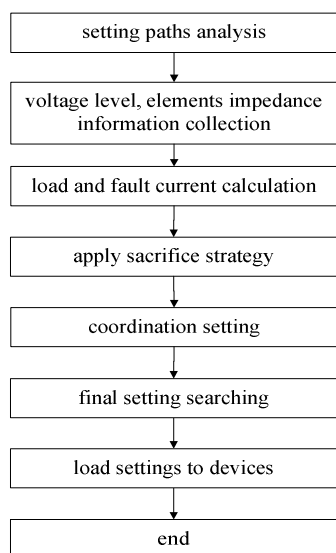
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Fig. 4 The processing flow of the protection scheme

A.   Setting paths analysis

The proposed protection scheme will take each feeder in the system as radial feeders equivalently firstly. From every substation which is in service, all the setting paths will be searched and stored separately. After all the setting paths are traversed for setting, the fastest setting of some devices which may have two or more sets of settings in one direction will be searched. And finally all of the objects of the same switch (same Id and same direction) will be loaded with the fastest value. Therefore, one other important job need to do in this stage is to mark the direction via attaching some flag (a head node identifier here) with each device.

Take the system in Fig.1 as the example, the analysis process means from S/S #1, the setting paths would be ① relay1, P1, P2 and P3, ② relay1, P1, P4, P5 and P6, ③ relay1, P1, P4, P5 and P7. Every subsequently one should coordinate with the previously one. And similarly the setting paths from S/S #2 can be found and stored.

Experientially, the setting paths are preferable to be stored using tree structure as shown in Fig. 5. And the memory addresses of the objects of same ID but of different direction are different.
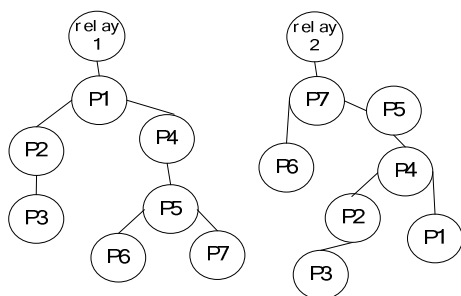

Fig. 5 Storage of setting paths

B.   Load and fault current calculation

To calculate the load and fault current of each device, the system was analyzed including the system configuration, voltage level, source impedances, and line impedances and so on. Then the load and fault current are computed with considering the issues discussed in section II and the values are documented for the next stage.

C.   Coordination settings for protection devices

To get the optimizing setting, the setting process will traverse every setting path twice. Taking use of the setting paths (the sacrifice of some devices has already been applied), for the first traverse, the setting begins with a OCR and one of its downstream reclosers, and then set the following downstream ones until the last one in the path is set. At this step, the maximum possible pickup which can offer maximal CTI margin is found for every protection device. For the second traverse, from the last ones in every setting path, reset them with the minimum possible operating value (less than the upper limit found in the previous step) to make the fault can be cleared as fast as possible.

Following this way, the setting order of the system shown in Fig. 1 would be: (1) first traverse, relay1, P1, P2, P3 and P4, P5, P6 and then P7, (2) second traverse, P7, P6, P5, P4 and P3, P2 and then P1. And so does the setting path from relay2.

While the status of the tie switches changed, it is necessary to analyze the system configuration and calculate the necessary data such as load current and fault current again to reset the protective devices. For instance, while a fault occurs between relay2 and P7, both of the two devices will operate to isolate the fault. Then a system reconstruction scheme that open tie switch2 and close tie switch3 will be produced, the next step the new configuration will be analyzed and the corresponding coordination settings will be calculated. If the new system configuration is feasible, the system will be reconstructed and the protective devices will be reset. At last another operation state is achieved.

IV. CASE STUDY AND RESULT VERIFICATION

The proposed setting method is realized using C++ program in this study. The input data of the program is documents specifying system configuration information and the necessary parameters of the devices, and the output is the setting values for each protective device if the setting succeeded, or the failure reason analysis if failed.

Fig. 6 shows a sample 33-bus distribution system with open and closed-loop which is used to apply the program to verify the setting algorithm discussed in this paper. The recloser in the system is assumed to KH-ESV, which is one of the automatic recloers produced by ABB and is widely used in the distribution system of South Korea. For such a type of recloser, operating curve (N1, N2, N3 and N4), sequence (fast (F) and delay (D)) and pickup all need to be set.

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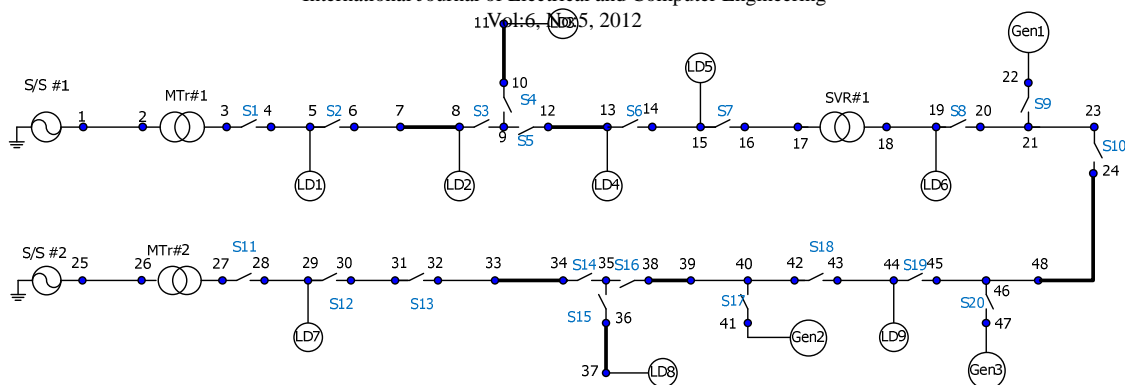Vol:6, No:5, 2012

Fig. 6 A 33-bus distribution system with closed-loop

The system was created by connecting three traditional radial distribution systems. All of these feeders have one over current relay near the substation, and several reclosers located separately in the down lines to minimize the power cut area when fault occurs. The setting result for each protective device is displayed in Table I. Here HD denotes the head node which is used to mark the direction, Seq is the abbreviation of operating sequence, Ip_fp and Ip_fg denotes the pickup current (A) for phase and ground fault respectively.

TABLE I
THE SETTING RESULT OF THE SAMPLE SYSTEM

Device ID	HD	curve	Seq	Ip_fp	Ip_fg
S1(OCR)	3	\	\	480	90
S2(Rec)	5	N2N4	1F3D	419.2	81
S4(Rec)	9	N1N3	1F2D	44.6	4.8
S18(Rec)	43	N2N4	1F2D	142.7	48.2
S12(Rec)	30	N1N3	1F1D	23.9	6.6
S15(Rec)	35	N1N3	1F1D	44.6	4.8
S11(OCR)	27	\	\	480	90
S13(Rec)	31	N2N4	1F3D	396.9	81
S15(Rec)	35	N1N3	1F1D	44.6	4.8
S6(Rec)	14	N2N4	1F2D	166.5	53.4
S2(Rec)	6	N1N3	1F1D	59.4	6.4
S4(Rec)	9	N1N3	1F2D	44.6	4.8

To verify the settings can satisfy the constraints in section I, the coordination curves of each pair of the devices in one path which are expected to coordinate with each other are plotted using MATLAB (Fig. 7). As shown in Fig. 6, S1, S2, S18 and S12 are in series around the loop, from the S1, all of these equipments were configured to coordinate with its backup. On the condition that the pickup of each device can see all the faults belong to its protection zone and less than the maximum normal current, as we can see from Fig.7, the coordination can be achieved when the most severe situation are encountered. That is to say, the primary device will always operate several cycles (which is greater than the CTI limit) before the backup when the fault is in the overlapping zone.
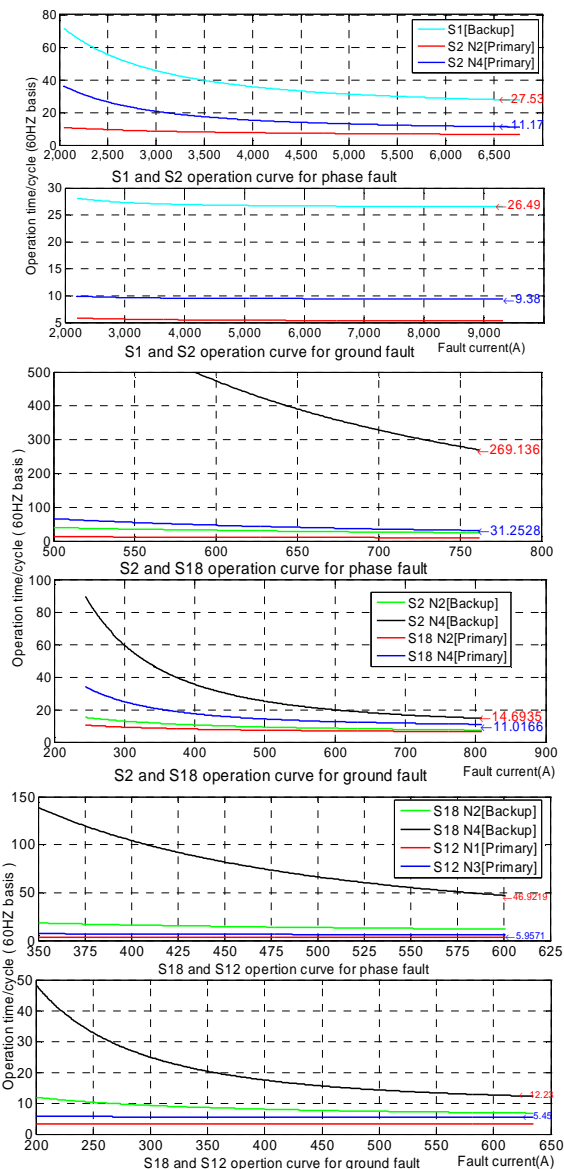

Fig. 7 Setting result verification

V. Conclusion

A generalized setting method of over current protection devices for distribution system with open and closed-loop was studied in this paper. The method takes account of all the basic factors in the over current protection theory, and analyzed the differences of these factors between the traditional distribution systems and the one with open and closed-loop. The method provides a generalized setting process of the distribution systems with open and closed-loop which is adaptive, reliable and easy to use. What is more, the clearance time of fault and the setting time are limited to the minimum level.

To apply the method to smart grid, the next stage of the study will focus on the effects of the distributed generator [9].

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